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EXOBIOLOGY SITE PRIORITIES FOR MARS PATHFINDER. J. D. Farmer and D. J. Des Marais, NASA Ames Research Center, Moffet Field CA 94035, USA.

Although present martian surface conditions appear unfavorable for life as we know it [1], there is compelling geological evidence that the climate of early Mars was much more Earth-like, with a denser atmosphere and abundant surface water [2]. Three key post-Viking discoveries mandate a more rigorous search for a martian biosphere. First, 3.5-b.y.-old fossils indicate that our own biosphere might be almost as old as Earth itself [3]. Second, climates on both Earth and Mars have evolved through time. Third, the range of Earth's habitable environments is greater than previously known. Extremes for terrestrial life include polar deserts, deep subsurface aquifers and hydrothermal systems, and high-salinity ponds and lakes. The fact that life developed on the Earth within the first billion years of its history makes it quite plausible that life may have also developed on Mars [4]. If life did develop on Mars, it undoubtedly left behind a fossil record. Such a fossil record is likely to be more accessible than either subsurface environments that may harbor life, or scattered "oases" that may be present at the surface. Consequently, the post-Viking approach of Mars exobiology has shifted focus to search for evidence of an ancient martian biosphere. This has led to the emergence of a new subdiscipline of paleontology, herein termed "exopaleontology" [5], which deals with the exploration for fossils on other planets and whose core concepts derive from Earth-based Precambrian paleontology, microbial ecology, and sedimentology [6,7].

By analogy with the Precambrian record of the Earth, an early martian biosphere is likely to have been microbial. The types of micropaleontological information we could expect to find on Mars include microbial body and trace fossils, biostratification structures (e.g., stromatolites), and biomolecular fossils. Based on what we have learned from the Precambrian record on Earth, the best preservation of microorganisms as fossils occurs when they are rapidly entombed by aqueous minerals while the organisms are still viable, or at least prior to cellular degradation [6,7]. For long-term preservation (i.e., billions of years), organic materials must be incorporated into or replaced by fine-grained, stable phases (e.g., silica, phosphate, or carbonate). Terrestrial microfossils were preserved in this way, being permineralized in siliceous sediments (cherts) associated with ancient volcanic terrains in Australia and South Africa [8,9].

The above observations lie at the core of the proposed exploration strategy to search for a fossil record on Mars. Terrestrial environments where high rates of aqueous mineral precipitation and microbial activity coincide include subaerial thermal springs and shallow hydrothermal systems, sublacustrine springs and evaporitic lakes, subsurface soils where "hardpans" (e.g., calcretes, silcretes) form, vadose zone karst deposits and silcretes associated with karst paleosols, and high-latitude frozen soils or ground ice [6,7].

Subaerial thermal spring deposits are key targets for a fossil record on Mars [10] because high rates of mineral precipitation may occur together with microbial activity. Volcanic terrains are widespread on Mars and some possess outflow channels that are likely to have formed by spring sapping [11]. The association of such features with potential heat sources, such as volcanic cones or thermokarst features, indicates the possibility of past hydrothermal activity on Mars. Within the landing site constraints for Mars Pathfinder, a number of potential exploration targets meet the basic requirements for hydrothermal activity and associated mineralization, based on analysis of Viking images. These include thermokarst features and areas possibly affected by hydrothermal processes, including (1) the head reaches of small channels in the Ares and Tiu Vallis outflow systems, which originate from areas of chaos, and (2) the floors of chasmata, such as Echus Chasma. Target deposits in such areas include the common subaerial spring minerals, silica and carbonate, as well as hydrothermal alteration halos associated with shallow igneous intrusives (including dike swarms) where hydrous clays may have been formed through hydrothermal alteration of host rocks.

Reliable identification of aqueous mineral phases requires that we incorporate rover-based techniques for *in situ* compositional analysis that provide structural information, in addition to elemental abundance. Target minerals for exopaleontology have characteristic signatures in the near- and midinfrared that should be detectable using rover-based spectroscopy. Future landed missions should incorporate such approaches, along with fiber-optic-based visible and UV microscopy, as standard payload exploration tools for Exopaleontology. Even if life never developed on Mars, aqueous mineral deposits still hold great interest as potential sources of information about the nature and abundance of the precursor organic molecules available in the early solar system. Fluid inclusions incorporated into aqueous minerals during their crystallization provide valuable samples of primary liquid and vapor phases and potentially microorganisms and biomolecules [12]. Although more research is needed, rover-based spectral analysis may provide a sensitive, *in situ* method for distinguishing fluid-inclusion-rich mineral deposits from "dry" rocks [13].

Through Earth-based analog studies, we have also been investigating the paleontology and sedimentology of subaqueous spring deposits formed over a range of temperatures as potential targets for Mars exopaleontology. Rates of mineral precipitation within such environments are often high enough to entomb associated microbial mat communities, and deposits formed at lower temperatures have the advantage of preserving a higher proportion of organic matter [14]. Thus, in contrast to subaerial thermal spring deposits, tufas and evaporites often contain abundant microbial fossils and organic matter. Sublacustrine springs are common in many water-rich volcanic settings, particularly in association with crater and caldera lakes [7]. Sediments deposited in such settings are frequently heavily mineralized and are important exploration targets for many types of economic ore deposits. Some of our finest examples of excellent preservation in the terrestrial fossil record are found in such facies [15].

In pluvial lake basins in western North America, subaqueous spring deposits and sedimentary cements are commonly found along the distal margins of fan delta deposits within mixing zones where fresh ground water encounters alkaline lake water [16,17]. In such terminal lake settings, evaporites are commonly deposited in basinward locations during lake low stands. Evaporite minerals frequently entrap halobacteria and organic matter within fluid inclusions during crystallization. Although the long-term viability of salt-entrapped organisms is debatable [18], entombed organics appear to survive for long periods of geologic time. Consequently, "evaporites" are regarded to be prime targets for Mars exopaleontology for reasons outlined above. The major disadvantage is that, in the presence of an active hydrological system, evaporites tend to have short crustal residence times and are easily lost from the stratigraphic record by dissolution. Thus, terrestrial evaporites are quite rare in Precambrian sequences. However, this may not apply to Mars. Given the early decline of a martian hydrological cycle involving liquid water, it is possible that Archean-aged evaporites have survived there.

Potential targets on Mars for subaqueous spring deposits, sedimentary cements, and evaporites are ancient terminal lake basins where hydrological systems could have endured for some time under arid conditions [19,20]. Potential targets for the Mars Pathfinder mission include channeled impact craters and areas of deranged drainage associated with outflows in northwest Arabia and Xanthe Terra, where water may have ponded temporarily to form lakes. The major uncertainty of such targets is their comparatively younger age and the potentially short duration of hydrological activity compared to older paleolake basins found in the southern hemisphere. However, it has been suggested that cycles of catastrophic flooding associated with Tharsis volcanism may have sustained a large body of water, Oceanus Borealis, in the northern plains area until quite late in martian history [21,22]. Although problematic, the shoreline areas of the proposed northern ocean (e.g., along the Isidis impact basin and the plains of Elysium, Chryse, and Amazonis) provide potential targets for a Mars Pathfinder mission aimed at exploring for carbonates or other potentially fossiliferous marine deposits. Carbonates and evaporites possess characteristic spectral signatures in the near-infrared [23] and should be detectable using rover-based spectroscopy and other methods for *in situ* mineralogical analysis.

Many terrestrial soils are known to preserve microbial fossils and biogenic fabrics within the mineralized subzones of soils, such as calcretes, silcretes, or other types of "hard-pans" [24]. For example, the oldest terrestrial microbiota are preserved in silcretes associated with 1.7-Ga karst. Viking biology experiments indicate that surface soils on Mars are highly oxidizing and destructive to organic compounds. However, mineralized soil horizons could protect fossil organic matter from oxidation and should not be overlooked as potential targets for exopaleontology. At the Viking Lander 2 site, soils showed the development of duricrust, suggesting cementation [25], and sulfate and carbonate minerals are inferred to be present in the martian regolith based on elemental analysis by X-ray fluoresence. Although Viking conclusively demonstrated the absence of organic compounds in the soils analyzed, the presence of cements in martian surface sediments suggests a possibility for hard-pan mineralization that could afford protection to organic materials against oxidation. The best places to explore for mineralized paleosols are deflational areas where wind erosion may have stripped away surface sediments, exposing indurated zones formed at depth. Such sites are widespread within the potential landing area for Mars Pathfinder.

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MARS PATHFINDER METEOROLOGICAL OBSERVATIONS ON THE BASIS OF RESULTS OF AN ATMOSPHERIC GLOBAL CIRCULATION MODEL. F. Forget, F. Hourdin, and O. Talagrand, Laboratoire de Météorologie Dynamique, E.N.S, Paris, France.

The Mars Pathfinder Meteorological Package (ASI/MET) will measure the local pressure, temperature, and winds at its future landing site, somewhere between the latitudes 0°N and 30°N.

Comparable measurements have already been obtained at the surface of Mars by the Viking Landers at 22°N (VL1) and 48°N (VL2), providing much useful information on the martian atmosphere. In particular, the pressure measurements contain very instructive information on the global atmospheric circulation. The large-amplitude seasonal oscillations of the pressure are due to the variations of the atmospheric mass (which result from condensation-sublimation of a substantial fraction of the atmospheric carbon dioxide in the polar caps), but also to internal latitudinal mass redistribution associated with atmospheric circulation.

The more rapid oscillations of the surface pressure, with periods of 2–5 sols, are signatures of the transient planetary waves that are present, at least in the northern hemisphere, during autumn and winter.

At the Laboratoire de Météorologie Dynamique (LMD), we have analyzed and simulated these measurements with a martian atmospheric global circulation model (GCM), which was the first to simulate the martian atmospheric circulation over more than 1 yr [1,2]. The model is able to reproduce rather accurately many observed features of the martian atmosphere, including the long- and short-period oscillations of the surface pressure observed by the Viking landers (Fig. 1).

Both the annual pressure cycle and the characteristics of the rapid oscillations have been shown to be highly variable with the location on the planet. For instance, simulated surface pressure obtained in the middle latitudes of the southern hemisphere look very different than the Viking landers measurements because of the effect of an opposite meteorological seasonal component. From this